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Indian Standard

SPECIFICATION FOR STANDARD HYDROPHONE

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Indian Standard

SPECIFICATION FOR STANDARD HYDROPHONE

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0. FOREWORD

0.1 This Indian Standard was adopted by the Indian Standards Institution on 30 May 1975, after the draft finalized by the Acoustics Sectional Committee had been approved by the Electrotechnical Division Council.

0.2 This standard covers the design requirements of standard piezoelectric hydrophones and the data required to specify their characteristics. Such requirements and characteristics are given as to specify the hydrophone to be suitable as a standard hydrophone for calibration purposes, to be used as a standard for comparison with other hydrophones that are intended for daily use.

0.3 While preparing this standard, assistance has been derived from IEC Pub 500 (1974) ' IEC Standard hydrophone ' issued by the International Electrotechnical Commission.

0.4 For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test, shall be rounded off in accordance with IS : 2-1960*. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

1. SCOPE

1.1 This standard covers the design requirements of standard piezoelectric hydrophones and the data required to specify their characteristics.

2. TERMINOLOGY

2.0 For the purpose of this standard, the terms and definitions covered in IS : 1885 (Part III/Sec 4)-1966† shall apply.

3. GENERAL DESCRIPTION

3.1 The requirements for a standard hydrophone, to be used as a reference for underwater sound pressure levels, are mainly concerned with its free

*Rules for rounding off numerical values (*revised*).

†Electrotechnical vocabulary: Part III Acoustics, Section 4 Sonics, ultrasonics and underwater acoustics.

field open-circuit voltage sensitivity (*see also* Appendix A). The following general requirements shall apply:

a) Over a frequency range of at least 3 decades, the sensitivity level shall be constant within 3 dB (that is ±1·5 dB). The lower limit of this frequency range will generally not be lower than 1 Hz and the upper limit will not exceed 100 kHz;

b) Between the temperature of 5°C and 30°C, the sensitivity level shall be constant within 1 dB (that is ± 0·5 dB);

c) Within a dynamic range of 60 dB, the output voltage of the hydrophone shall be linear with the free field sound pressure within 1 dB (that is ± 0·5 dB);

d) At any depth between 0 and 10 metres the sensitivity level shall not differ by more than ± 0·5 dB from the nominal value; and

e) The stability of the hydrophone shall be such that a calibration can hold good for a period of at least one year. The hydrophone should, therefore, preferably be recalibrated at intervals not longer than one year.

3.2 The sensor shall be of the piezoelectric type, either with a piezoelectric single crystal or a piezoelectric ceramic element.

3.2.1 The sensor material, however, shall be selected carefully in order to meet the specific requirements (*see* **A-1.2**).

4. FREE FIELD OPEN CIRCUIT VOLTAGE SENSITIVITY

4.1 Over the specified frequency and dynamic ranges the free field open-circuit voltage sensitivity level of the standard hydrophone shall be from −170 dB to −210 dB re 1 V per micropascal (or −70 dB to −110 dB re 1 V per microbar) (*see* **A-1.3**).

4.2 The frequency response of a piezoelectric hydrophone has a flat part limited at the lower frequency end by the lower cut-off frequency due to the capacitance of the piezoelectric element and the resistive load on this capacitance. At the high frequency end the sensitivity may change either by diffraction effects or as a result of mechanical resonance of the sensor element.

4.2.1 Approximately one octave below this resonance frequency the frequency response curve starts to rise. In accordance with **3.1**(a) the deviation in the flat part of the frequency response curve shall be less than 3 dB over at least three frequency decades. Hence the lower cut-off frequency and the resonance frequency shall be at least four decades apart.

5. DIRECTIVITY

5.1 For free field calibrations, the standard hydrophone shall be omnidirectional in azimuth. The deviation from an ideal omnidirectional pattern should not exceed 3 dB.

6. ELECTRICAL REQUIREMENTS

6.1 The hydrophone shall be connected to a cable of shielded construction with a length of at least 10 metres. The end-of-cable leakage resistance shall be at least 100 megohm, the test voltage being 100 V.

6.2 Electrical shielding of the high impedance sensor element of the hydrophone housing and shield shall be connected to the cable shield. If the sensor element has a capacitance smaller than the capacitance of the cable, a preamplifier shall be incorporated.

6.3 For the calibration of a complete signal measuring system, a resistor of 1 to 10 ohm shall be inserted between the sensor element and the lower side of the preamplifier input. Insertion of a calibrated electrical signal across this resistor through two wires in the cable, independent of the preamplifier output circuit, yields an overall calibration of the hydrophone, analyser, tape recorder or other auxiliary equipment. In any case the sensor element ground connection shall be kept separate from the hydrophone case and cable shield.

NOTE — Calibration of the system by the insert voltage technique is valid only when the shunt capacitance of the cable has an impedance much greater than the insert resistance.

6.4 Long cables at higher frequency will alter the measured end-of-cable open-circuit voltage due to cable losses and standing waves. Under these conditions a cable terminated at each end by its characteristic impedance shall be used.

6.5 Both sides of the calibration resistor shall be connected to separate wires in the cable, so that the calibration current does not flow through the earth lead of the output signal, nor through the cable shield. Crosstalk between the calibration signal and the output signal shall be less than −40 dB.

7. SENSOR ELEMENT

7.1 The sensor element shall be acoustically stiff relative to its environment (that is, its volume compliance shall be less than that of an equivalent volume of water) so that its presence in a coupler calibrator for low frequency calibration does not affect the pressure level. In this way the free field calibration is obtained.

NOTE — This characteristic is also useful in a free field comparison calibration when the standard and the unknown are simultaneously immersed in the sound field. If the hydrophone dimensions are small in relation to the wavelength of sound, the presence of an acoustically stiff hydrophone will not noticeably alter the free field sound pressure.

7.2 The suspension of the sensor element shall be such that the frequency of mechanical resonance, caused by the mass of the element and the compliance of the suspension falls below the specified frequency range.

NOTE — At this resonance frequency the movement of the element induced by the vibration of the preamplifier case may generate a voltage across the sensor terminal and the hydrophone may be sensitive to a pressure gradient.

7.3 A sensor element which is small enough to be omnidirectional in azimuth may have a low sensitivity or a low capacitance, or both. The sensitivity level shall not be below the minimum value given in **4**. The capacitance should preferably not be lower than the shunt capacitance formed by the connecting wires and the preamplifier input circuitry.

NOTE — In order to increase the capacitance without affecting the sensitivity, an array or multiple elements, mechanically uncoupled but electrically connected in parallel, may be extended in the vertical direction. It should be borne in mind that the length of the array determines the vertical directivity at the upper limits of the useful frequency range. The size of the individual elements determines the frequency of mechanical resonance and hence the upper limit of the useful frequency range.

8. OTHER REQUIREMENTS

8.1 Supporting Structure — The hydrophone will require some support structure for positioning it in the sound field. In a typical design the sensor element is housed in an acoustically transparent capsule beneath the preamplifier case with the cable coming out at the top. The support structure is attached to the preamplifier case or the cable. The directivity in the vertical plane shall be such that the influence of the preamplifier case and the supporting structure on the sensitivity does not exceed 1 dB in the frequency range specified by the manufacturer according to **9.1**.

8.2 Exposed Metal Parts — All metal parts of the hydrophone exposed to water shall be made of corrosion resistant material. The use of different metals shall be avoided because of galvanic corrosion that may occur. It is generally desirable to coat all metal parts with an elastomer.

NOTE — The existence of potential differences between different parts of the case when the hydrophone is immersed in sea water may give rise to electrical noise in the system.

8.2.1 Exposed metal parts of hydrophone housing and electrostatic shield shall be connected to the cable shield (*see* **6.2**).

9. REQUIREMENTS FOR STANDARD HYDROPHONE

9.1 The specification of characteristics and requirements for standard hydrophone shall be as given in Table 1 (*see also* Appendix A).

TABLE 1 CHARACTERISTICS AND REQUIREMENTS FOR STANDARD HYDROPHONE

(*Clause* 9.1)

SL No.	CHARACTERISTIC	REQUIREMENT
(1)	(2)	(3)
i)	Free field open-circuit voltage sensitivity:	
	a) Frequency of fundamental mechanical resonance of the sensor	> 100 kHz
	b) Frequency range of flat frequency response curve within 3 dB limits	At least 3 decades within 1 Hz to 100 kHz
	c) Sensitivity level in flat part of frequency response	— 170 to — 210 dB re 1 V/µ Pa
ii)	Hydrophone without preamplifier:	
	a) Frequency response curve of end-of-cable sensitivity	
	b) Frequency response curve of end-of-cable capacitance	
	c) Frequency response curve of end-of-cable leakage resistance	> 100 MΩ
iii)	Hydrophone with preamplifier:	
	a) Hydrophone (sensor element):	
	1) Frequency response curve of open-circuit voltage sensitivity	
	2) Capacitance in pF	
	b) Preamplifier:	
	1) Frequency response curve	
	2) Nominal gain in dB	
	3) Input impedance in ohm	
	4) Output impedance in ohm	
	5) Minimum allowable load impedance in ohm	
	6) Characteristic impedance of cable in ohm	
	7) Maximum output signal level in dB re 1 V	
	8) Overload sound pressure level in dB re 1 µ Pa	
	9) Maximum safe peak sound pressure level in dB re 1 µ Pa	
	10) Curve of equivalent noise pressure spectrum level versus frequency	
	11) Maximum value of equivalent noise pressure spectrum level in dB re 1 µ Pa $S^{\frac{1}{2}}$	
	12) Dynamic range	> 60 dB
	13) Calibration provision, value of insert voltage resistor	10 ohms ± 1 %
	14) Circuit diagram showing the connections between hydrophone (sensor element) preamplifier, insert voltage resistor, cable, screens and exposed metal parts	

(*Continued*)

TABLE 1 CHARACTERISTICS AND REQUIREMENTS FOR STANDARD HYDROPHONE — *Contd.*

SL No. (1)	CHARACTERISTIC (2)	REQUIREMENT (3)
iv)	Directivity:	
	a) Horizontal and vertical directivity patterns at four specified preferred frequencies chosen from IS : 2264-1963*	
	b) Equivalent line length up to the high frequency limit in mm	
v)	Sensor element:	
	a) Element material	
	b) Size of sensor element in mm^3	
vi)	Electrical parameters:	
	a) Type of electrostatic shield	
	b) Diagram of cable connections	
	c) Power requirements:	
	1) Power supply voltage to preamplifier in V	
	2) Current drain in mA	
	3) Maximum ripple allowed in percentage	
	4) Required stability in percentage	
	5) Source impedance in ohm	
vii)	Mechanical parameters:	
	a) Type of exposed metal	
	b) Type of exposed rubber	
	c) Type of oil	
	d) Position of sensor element	
	e) Cable length in m	> 10 metres
	f) Size without cable in mm	
	g) Weight with cable in kg	
viii)	Environmental factors:	
	a) Operating temperature range	5 to 30°C
	b) Variation of free field open-circuit voltage sensitivity level over the specified temperature range	Not more than ± 0·5
	c) Maximum operating depth	Not less than 10 metres
	d) Variation of free field open-circuit voltage sensitivity level over the specified depth range	Not more than ± 0·5 dB between 0 and 10 metres
	e) Storage temperature range in °C	
	f) Sensitivity to sunlight, oxygen, chemicals, ionizing radiation and mechanical shock	

NOTE — The manufacturer of the hydrophone shall specify the values for all the characteristics given in the table. For such characteristics for which values have been indicated, the values declared by the manufacturer shall be better than those specified.

*Preferred frequencies for acoustical measurements.

APPENDIX A

(*Clauses* 3.1, 3.2.1, 4.1 *and* 9.1)

GUIDANCE ON HYDROPHONE CHARACTERISTICS

A-1. DESIGN REQUIREMENTS

A-1.1 General

A-1.1.1 In underwater acoustics the primary standard for sound pressure measurements is the hydrophone. Unlike airborne sound, where the condensor microphone is so widely used, the hydrophone is generally of the piezoelectric type with a built-in preamplifier.

A-1.1.2 Maximum operating frequency range and stability with age, minimum equivalent noise pressure level and sensitivity change in ambient temperature and operating depth are some of the aspects the designer of the hydrophone needs to consider.

A-1.1.3 A standard hydrophone should consist of a sensor element and a built-in preamplifier. This combination serves two following purposes:

a) The output impedance is constant over a large frequency range, and has a low resistive value, thus providing assurance that the effective open-circuit voltage is measured throughout the operating frequency band by connecting the sensor element to a device with a high input impedance or by the use of the calibration resistor.

b) It ensures that the standard hydrophone cannot be used as a source, thus avoiding the possibility of damaging the sensor by overloading.

This configuration will have a constant free-field voltage sensitivity over a broad frequency range below the frequency of mechanical resonance.

A-1.1.4 At a low frequency the capacitive reactance will equal the electrical leakage resistance across the sensor in combination with the preamplifier input impedance. The sensitivity at this frequency will be 3 dB below the constant sensitivity at higher frequencies and the sensitivity will continue to decrease 6 dB per octave as the frequency is lowered.

A-1.1.5 The upper limit of the useful frequency range is determined by the frequency of mechanical resonance of the piezoelectric element. A high resonance frequency requires a small element, but this small size limits the obtainable capacitance and sensitivity. A high stability will only be obtained with a relatively insensitive material. Hence a large frequency range and a high stability are difficult to combine with a high sensitivity.

A-1.1.6 The high specific acoustic impedance of the water may create multiple paths of coupling between the water and the piezoelectric element through the hydrophone housing and the cable. Anomalies in the sensitivity and the directivity as a function of frequency, temperature and operating depth may then occur.

A-1.1.7 The sensor element may consist either of a stack of piezoelectric crystals or of a single piezoceramic element or of a group of ceramic elements. The sensor material shall be selected carefully in order to meet the requirements specified in **3**.

A-1.2 Sensor Material

A-1.2.1 The standard hydrophone should use lithium sulphate or one of the piezoelectric ceramics such as lead metaniobate or lead zirconate compositions. These ceramics are not as stable with time, temperature and depth as lithium sulphate, but they will yield a hydrophone having a lower equivalent noise pressure level for the same directivity and bandwidth.

A-1.2.2 The sensitivity of lithium sulphate will change less than one percent from 0 to 1 600 m and from 20 to 0°C. By comparison lead metaniobate will change 1·5 percent and lead zirconate titanate 2 to 3 percent over the same range of depth and temperature.

A-1.2.3 Ageing or prolonged stress will not affect the sensitivity of lithium sulphate but will affect the piezoelectric ceramics. Other piezoelectric crystals have either a lower dielectric constant (tourmaline), or require an unstable isolation material to shield two or more surfaces from the sound field [for example, ammonium dihydrogen phosphate (ADP), Rochelle salt].

A-1.3 Sensitivity

A-1.3.1 The sensitivity of the standard hydrophone shall be as specified in **4** and its self noise level shall preferably be closed to the background noise level.

A-1.4 Signal Lead Balance — The calibration of the hydrophone is usually done with an unbalanced connection since no electroacoustic device can be truly balanced electrically due to unbalanced stray capacitance.

A-1.5 Optimum Capacitance

A-1.5.1 A hydrophone for the measurement of low signal levels over a large ultrasonic frequency range has a small sensitive element with either a low capacitance or a low sensitivity or both.

A-1.5.2 For a given size of element and a given cable capacitance the electrode-configuration shall be chosen such that the element's capacitance is equal to the cable capacitance, while for a high sensitivity the cable capacitance should be low.

A-1.5.3 Hydrophones to be used at high ultrasonic frequencies, therefore, require a preamplifier close to the sensor element.

A-1.6 Amplifier Input Resistance — The input resistance R of the preamplifier should be sufficiently large that the cut-off frequency is not higher than the lower limit of the useful frequency range. The higher the resistance R, the lower the thermal noise of this resistor will be at the input of the amplifier. An input resistor of a built-in preamplifier of the order of 100 megohm is quite normal.

A-1.7 Equivalent Noise Pressure Threshold Level

A-1.7.1 The equivalent noise pressure threshold level of a hydrophone is determined by the electronic noise level at the input of the preamplifier and the sensitivity of the sensor element. Restrictions in this sensitivity and the capacitance of the sensor as a result of high-frequency requirements put a lower limit to the noise pressure threshold level.

A-1.7.2 Reduction of this threshold is possible either by increasing the size of the sensor, but this reduces the upper frequency limit, or by using more sensitive material, such as one of the piezoelectric ceramics instead of lithium sulphate. With lead metaniobate, for example, the noise threshold level will be 3 dB lower, with lead zirconate titanate the level will be 8 to 15 dB lower, as compared to lithium sulphate.

A-1.8 Mechanical Design

A-1.8.1 The stability of a hydrophone with age, ambient temperature and operating depth is dependent upon the sensor element and the means of coupling the element to the sound field. The acoustic properties of the coupling medium, for example some plastics or rubbers, may change with temperature or due to moisture absorption. The presence of gas bubbles or gas filled materials for gaskets or mechanical isolation will alter the sensitivity of the hydrophone as a function of operating depth.

A-1.8.2 The directivity may vary as a function of depth, particularly if there exist multiple paths of coupling between the water and the sensor element. In one or more of these paths the coupling can easily vary with depth if compression type gaskets are used in the construction. O-ring seals are not so severely affected by pressure.

A-1.8.3 The sensitiviy of the hydrophone should be unaffected by the support structure. The transference of vibrations from the cable should be minimized. For example, the sensor element may be simply suspended

on a light metal frame with rubber fittings, and coupled to the sound field through castor oil and a butyl rubber boot. The suspension structure would be clamped on a heavy metal case that houses the preamplifier.

A-1.8.4 Such a flexible sensor support and a heavy preamplifier housing will de-couple the sensor element from the cable vibrations. A combination of sensor element directivity and remoteness from the point of attachment of the hydrophone support structure will minimize the structure's effect upon the measured sound field.

A-1.8.5 In this design the butyl rubber minimizes water vapour penetration and the castor oil will absorb some water, thus prolonging the life of the hydrophone. In time, the presence of water on the surface of the sensor element will lower its leakage resistance and reduce its sensitivity at low frequencies.

A-1.8.6 At the frequency of mechanical resonance, caused by the mass of the sensor element and the compliance of its support, the sensor may be excited by the pressure gradient in the sound field and produce a voltage across the sensor. Thus the hydrophone may be sensitive to a pressure gradient at low frequencies. This is a problem particularly in the calibration of the hydrophone where the short distance from the source to the hydrophone increases the ratio of pressure gradient to sound pressure.

A-2. INDICATIONS OF HYDROPHONE DETERIORATION

A-2.1 There are generally distinctive signs that a hydrophone has deteriorated and can therefore no longer be relied upon as a standard. Most of these indications appear in the low frequency range and can be detected by means of a closed chamber calibration method.

A-2.2 If moisture has penetrated to the sensor element then the low cut-off frequency will increase.

A-2.3 The oil in which the sensor is immersed should be carefully de-aerated during the construction of the hydrophone. The presence of a small gas bubble in the oil due to poor workmanship, chemical action or subsequent leakage of air into the oil will produce a higher volume compliance of the hydrophone at low frequencies and a spurious resonance. For example, at shallow operating depths, a bubble of 5 mm diameter resonates at about 1 250 Hz, and will affect the sensitivity by 2 to 4 dB at resonance and about 1 dB below resonance. Smaller bubbles, which resonate at higher frequencies, will produce a lesser effect.

A-2.4 An increase in hydrostatic pressure will increase the resonant frequency of the bubble. Calibration of the hydrophone inside a closed chamber at the lower frequency range may reveal the presence of an air bubble.

A-2.5 Other causes of hydrophone deterioration are he following:

a) The presence of free sulphur in the oil, coming from the rubber boot or from metal parts in contact with the oil, may destroy the silver electrodes on the sensor.

b) Poor or deteriorated cement bonds reduce the acoustic coupling; fractured sensor elements reduce the element's capacitance; both failures lower the sensitivity in the constant-sensitivity frequency range and alter the character of the frequency response curve and of the directivity patterns.

c) High stresses developed during deep submergence may change the sensitivity of a piezoelectric ceramic element permanently.

d) Exposure to sunlight may overheat the sensor element, and thus lower its sensitivity.

A-2.6 All these deteriorations mentioned in **A-2.1** to **A-2.1.5** can be detected by a routine check of the frequency response curve of the hydrophone inside a closed chamber calibration unit.

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ACOUSTICS

IS :

1885 (Part III/Sec 1)-1965 Electrotechnical vocabulary: Part III Acoustics, Section 1 Physical acoustics

1885 (Part III/Sec 2)-1966 Electrotechnical vocabulary: Part III Acoustics, Section 2 Acoustical and electro-acoustical systems

1885 (Part III/Sec 3)-1967 Electrotechnical vocabulary: Part III Acoustics, Section 3 Sound recording and reproduction

1885 (Part III/Sec 4)-1966 Electrotechnical vocabulary: Part III Acoustics, Section 4 Sonics, ultrasonics and underwater acoustics

1885 (Part III/Sec 5)-1966 Electrotechnical vocabulary: Part III Acoustics, Section 5 Speech and hearing

1885 (Part III/Sec 6)-1967 Electrotechnical vocabulary: Part III Acoustics, Section 6 Acoustical instruments

2032 (Part XII)-1969 Graphical symbols used in electrotechnology: Part XII Electro-acoustic transducers, recording and reproduction systems

2264-1963 Preferred frequencies for acoustical measurements

2748-1964 Methods of measurements on microphones

3932-1966 Sound level meters for general purpose use

6964-1973 Octave, half-octave and third-octave band filters for analysis of sound and vibrations

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